An evaluation of the use of tooth temperature to assess human pulp vitality

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Abstract

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Aim To evaluate change in tooth surface temperature following a thermal stimulus as a simple and reliable method to assess the presence and the extent of blood flow through teeth.

Methodology Miniature thermometers were used to measure the relationship between surface temperature of teeth and internal flow of 37 °C water (*in vitro*) or blood (*in vivo*). In addition, thermal stimuli were applied to the external surface of the teeth, and the rate of temperature recovery was related to internal flow.

Results Under *in vitro* conditions, the surface temperature of teeth and rate of temperature recovery were related to the rate of internal water flow. However, *in vivo* neither standing surface temperature ($P = 0.47$) nor rate of temperature recovery ($P = 0.19$) were significantly related to evidential pulp vitality.

Conclusion Change in the surface temperature of teeth is not suitable as a simple clinical means to assess pulp vitality.

Keywords: blood flow, dental pulp, dental pulp test, investigative techniques, pulp vitality, temperature.

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Introduction

An assessment of the blood supply to the dental pulp would be useful in many circumstances. The diagnosis of oro-facial pain, the investigation of the pathophysiology of cervical sensitivity, the prognosis of abutment teeth in restorative treatment planning and the recovery potential for traumatized teeth would all benefit from such a measurement. Unfortunately, assessment of the pulpal blood supply remains complicated and there is no practical clinical test to determine this basic aspect of the tooth's biology.

The most common method used to assess the condition of the pulp has been to test the reaction of the nerve supply within the pulp, either thermally or electrically. Petersson *et al.* (1999) recently evaluated the ability of these methods to register pulp vitality. It was determined that both methods gave false positive and false negative values in the region of 10–16%. Within the last decade, laser Doppler flowmetry (LDF) has been assessed as a tool to measure pulpal blood flow. Whilst this technique has proved effective and reliable for some body tissues (Belcaro *et al.* 2000, Braverman 2000, Tabrizchi & Pugsley 2000), the limited translucency and multiple reflectance of teeth have cast doubt upon its validity to assess the condition of the pulp (Ikawa *et al.* 1999). Some workers have found this technique to be highly reliable, but only under specific and carefully controlled conditions (Evans *et al.* 1999). Furthermore, the cost of the necessary equipment makes it unlikely that LDF will become a popular or widely used technique.

Fanibunda (1986a) reported there was no difference in the surface temperature of vital and nonvital teeth despite the expectation that a normal pulp blood supply would have led to a higher temperature. It was concluded that the effect of the pulpal blood supply was masked by the heat exchange between the

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tooth, the environment and the supporting tissues (Fanibunda 1985). However, Fanibunda (1986a,b) suggested that it would be possible to relate pulpal blood supply to the rate of return of surface tooth temperature to normal after the application of a thermal change (either hot or cold). As a cold stimulus, Fanibunda wetted the tooth with saliva and measured the temperature whilst the tooth was subsequently exposed by opening of the mouth. The latent heat of evaporation of surface moisture caused a drop in temperature. The temperature fell sharply and then slowly recovered to an equilibrium temperature. It was suggested that the time taken to reach equilibrium depended on the pulp blood supply.

Thermographic imaging (TI) has also been used to measure tooth surface temperature (Egg *et al.* 1975, Pogrel *et al.* 1989, Kells *et al.* 2000a,b).

The work of Pogrel *et al.* (1989) supported the findings of Fanibunda (1986b) that, after cooling, vital teeth would rewarm more quickly than nonvital teeth. They also noted a disruptive effect of mouth air currents, and advocated the isolation of the teeth by rubber dam to exclude this effect.

Kells *et al.* (2000a,b) isolated the eight most anterior upper teeth in human subjects with heavy black rubber dam and measured tooth surface temperature using TI. They established that following isolation it took about 15 min for tooth temperature to stabilize. Despite isolation from respiratory air currents from both the mouth and the nose, they noted a significant cooling effect by room air currents.

Thermographic imaging is accurate, allows comparison of different areas of a tooth, and is entirely noninvasive. However, it requires considerable technical expertise and demands rigorous standardization of the experimental environment. Similarly to LDF it is valuable as an experimental tool, but has limited prospect of becoming a common clinical investigation in the near future.

The current study was undertaken to determine if an array of miniature thermometers could be used to investigate the thermal properties of a tooth in a simple and reliable way.

Materials and methods

In vitro experiments

A laboratory experiment was designed to simulate the effect of different internal flow rates on the surface temperature of a tooth. An attempt was made to simulate heat exchange from the gingivae and socket by immersing the roots of the tooth in a water bath held at 37 °C. An unrestored maxillary premolar tooth, recently extracted for orthodontic purposes, and immediately stored in 0.12% Thymol, was used for the experiment. In order to conserve coronal tissue, pulpal access was not made through the occlusal surface, but rather in an apico-coronal direction. The two existing root canals were instrumented in an apico-coronal direction with a size 20 K-file, followed by Nos. 2 and 3 Gates-Glidden burs. The tooth was then immersed in 5% sodium hypochlorite solution for 48 h, and then flushed through thoroughly to remove the pulp chamber contents. The exposed surface of the tooth was held in air at ambient laboratory temperature (maintained at 21 °C) and boxed-in by expanded polystyrene to provide protection from air currents. The surface temperature of the tooth was measured by an array of miniature Type B platinum resistance thermometers (DM301; Labfacility Ltd, Teddington, UK). The dimensions of the thermometers were 2.3 mm high, 2 mm wide and 1 mm thick, with a resolution of ±0.01 °C.

Three thermometers were arranged in an array. This array was placed on the tooth in a similar way to the *in vivo* experiment illustrated in Fig. 1. Two thermometers were placed so as to lie against the buccal surface of the tooth: one at the junction of the cervical and middle third (cervical thermometer), and one in the middle of the incisal third (incisal thermometer). The third thermometer was positioned out of contact with the tooth surface, with its sensitive surface perpendicular to the tooth's surface (air thermometer). A matrix of light cured acrylic (Triad; Dentsply, Weybridge, UK) was

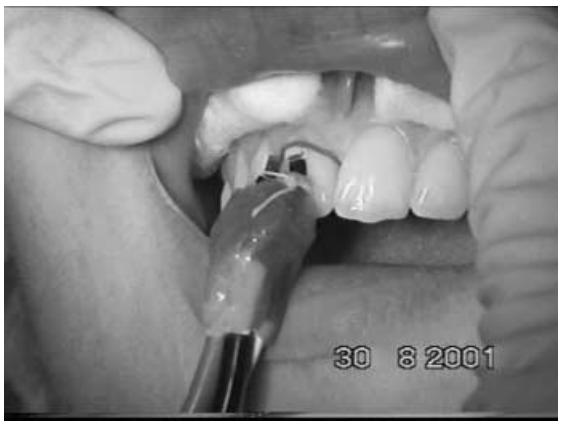

Figure 1 Tooth surface temperature recording.

used to enclose the cables and terminals of the three thermometers, and also the body of the incisal thermometer. The acrylic matrix was shaped to incorporate a ledge to assist consistent location against the incisal edge, and a horizontal groove to assist retention of the thermometer array on to the tooth. The bodies of the air thermometer, and of the cervical thermometer were unenclosed by the acrylic. However, the cervical thermometer had a small amount of acrylic placed on its external surface. This acrylic included a horizontal groove, to assist close adaptation of this thermometer to the tooth's surface.

The thermometer array was attached to the tooth using a suitably sized orthodontic elastic that was placed around the cervical aspect of the tooth. This was run through the acrylic groove on the external surface of the cervical thermometer to retain it against the labial surface of the tooth (similar to Fig. 1). A length of dental floss was run through the second groove as an additional means of retention and to optimize contact. Temperature readings from the thermometers were logged once per second by a personal computer.

The two instrumented root canals were used to provide input and output channels for water at 37 °C to be forced through the pulp chamber at a flow rate determined by an infusion pump. Beginning with zero flow, flow rates were increased at 10 mL h^{-1} increments to a maximum of 90 mL h^{-1}, each flow rate being maintained for a period of 15 min, sufficient for a new equilibrium temperature to be reached.

In a second *in vitro* experiment, the same tooth was initially cooled for 10 min by holding it in contact with a polythene bag of iced water. There was no flow during the cooling period. Recordings were then taken as the tooth rewarmed over a 4-min period at different flow rates.

In vivo experiments

Sixteen *in vivo* recordings were carried out on 10 subjects (four female, six male) with an age range of 21–58 years. Local area ethical committee approval was obtained for the experiments and subjects gave written consent prior to participating. Each subject had at least one tooth where a strong presumption of vitality could be made. Five of the subjects also had a matching contralateral nonvital tooth (three with root fillings, one sclerosed, one untreated and symptomless). The teeth studied were restricted to maxillary anterior teeth to optimize access and reproducibility. They consisted of 14 central incisors and two lateral incisors. Each tooth was examined and found to have no restorations other than small single surface resin fillings, except that three of the nonvital teeth were root filled. The electrical responsiveness of all the teeth assessed was measured prior to the experiment using an electric pulp tester (Kerr Vitality Scanner; Kerr, Peterborough, UK). The tooth and surrounding tissues were dried using gauze and probe to tooth conductance was enhanced by gel toothpaste. Circuit disconnection was subject controlled. Radiographs were assessed for periodontal widening, loss of lamina dura or periapical radiolucency. The results of these investigations were found to be in agreement with the presumed vitality.

Subjects were seated comfortably in a dental chair. Ambient clinic temperature was approximately 21 °C. The operating light (Kavosun; Kavo, Biberach, Germany) was placed between 45 and 55 cm from the patient. A maxillary anterior tooth was isolated from the soft tissues with cotton wool rolls, and the enamel surface of the tooth cleaned and dried with gauze.

As in the *in vitro* experiments, a thermometer array was held against the labial aspect of the tooth, primarily by means of an orthodontic elastic. A length of dental floss was used as a second means of retention, and adjustment of the tension in this allowed contact between thermometer and tooth to be optimized (Fig. 1). The entire experiment lasted 15 min: the initial temperature of the tooth was recorded for the first minute; the tooth was then cooled using an air/water jet for 20 s followed by a sustained jet of air (at approximately room temperature) for 10 min. To encourage airflow around the tooth under investigation, an active aspirator tip was held palatal to the tooth during this period. Finally, the recovery temperature of the tooth was recorded during a further 4 min. In the five subjects who only had vital teeth, measurements were made on a maxillary central incisor tooth. The remaining five subjects each had at least one nonvital tooth, three of which were maxillary central incisors and two maxillary lateral incisors. Two experiments were carried out on these subjects: one on the nonvital tooth and a second, for comparison, on the contralateral tooth, which was assumed vital in each case.

The initial temperatures of vital and nonvital teeth were compared using a one-tailed *t*-test. The recovery rates of vital and nonvital teeth were compared by application to a binomial distribution with an assumed probability of 0.5.

Results

In vitro experiments

Results from the first experiment show the final tooth surface temperature as the flow rate through the pulp cavity was increased (Fig. 2). The temperatures increase rapidly with increasing flow rates until 40 mL h^{-1}, after which the increases are less rapid.

Figure 3 demonstrates the temperature recovery against time after cooling the tooth. The 0 mL h^{-1} curve shows that the temperature increased over the 4-min recovery period although there was no fluid flow through the pulp space. A flow rate of 40 mL h^{-1} resulted in more rapid rewarming, and flow at 70 mL h^{-1} even more rapid. Rate of rewarming appeared to be affected by internal flow rate, although this was not a simple proportional relationship.

In vivo experiments

In the first part of the *in vivo* studies, tooth temperature was measured before cooling the tooth. Figure 4 shows a histogram of the initial temperatures of the 16 teeth, five of which were nonvital. No difference is evident between the two populations ($P = 0.47$).

After cooling as described for 10 min, teeth were allowed to rewarm whilst their temperatures were monitored for a further 4 min. Figure 5 shows a composite plot of these temperature changes for the individual teeth.

Finally, Fig. 6 shows each individual nonvital tooth temperature recovery curve compared with that of the contralateral vital tooth. In four of five cases, the recovery of the vital tooth was more rapid. For a binomial distribution with an assumed chance of success of 0.5, this returns a calculated probability of 0.1875.

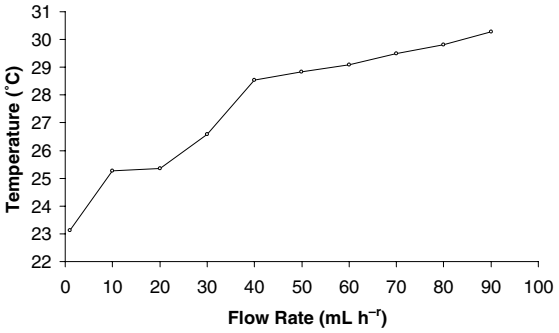

Figure 2 Final surface temperature of an extracted tooth at various rates of perfusion of the pulp with water at 37 °C.

Discussion

An array of three thermometers was used. Two thermometers were placed in contact with the tooth to allow a temperature differential to be measured across different parts of the tooth. It was hypothesized that the rate of rewarming would vary in different areas of the tooth. Two measurements would allow this gradient to be quantified in space or in time, or a derivative of these. In addition, it was postulated that having two thermometers on the tooth would allow the exclusion of common influences. The purpose of the air thermometer was to allow environmental effects on local temperature to be taken into account. In the event, none of these contingencies proved productive.

As the thermometer sensor surface is flat, and the tooth surface is convex, contact between them was not continuous. Floss was found to allow optimum control of the positioning of the thermometer, so as to maximize contact. Thermally conductive paste was not used, due to concerns about reduction of direct contact and of potential toxicity in the *in vivo* experiments.

Subjects were asked to avoid mouth breathing. In the presence of mouth breathing, the cycle of respiration is evident in a 5–10-s periodicity in the recorded temperature. This was never a noticeable feature in any of the experiments, and the subjects generally complied with the instruction not to mouth breathe. Despite having decided upon a utilitarian approach, the effect of rubber dam was tested in a pilot experiment (Fig. 7). The tooth isolated with rubber dam has a generally higher temperature, both initially and during rewarming. However, in the absence of any conspicuous effect on the stability of the recorded temperature, routine use of rubber dam was not implemented.

In addition, it became clear during pilot experiments that during cooling with the air jet, the temperature of the tooth took some time to reach a stable state (Fig. 8). During the sustained air jet on the teeth and thermometers, there was a slow rise in temperature. The rise is similar to that described by Kells *et al.* (2000a), although noticeably steeper. The recorded temperature was stable after 6–7 min of cooling. To allow for individual variation, a cooling time of 10 min was used.

A cooling time of 10 min was also expected to allow cooling of the entire bulk of enamel and dentine to the temperature of the air jet. This expectation was based on observations from the *in vitro* experiments, where temperatures reached a steady-state after 3–7 min,

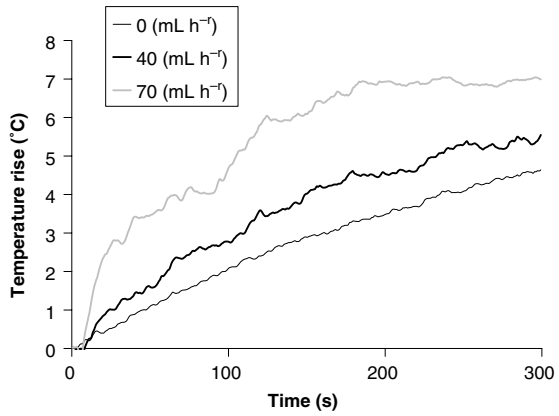

Figure 3 The surface temperature of the extracted tooth as it recovered from cooling with ice/water for 10 min. Three different flow rates are shown.

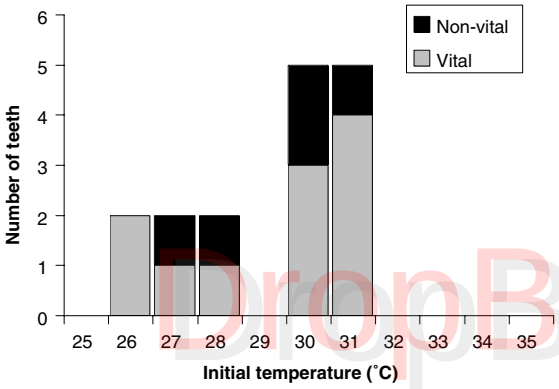

Figure 4 A histogram of the initial surface temperatures of 11 vital and five nonvital teeth.

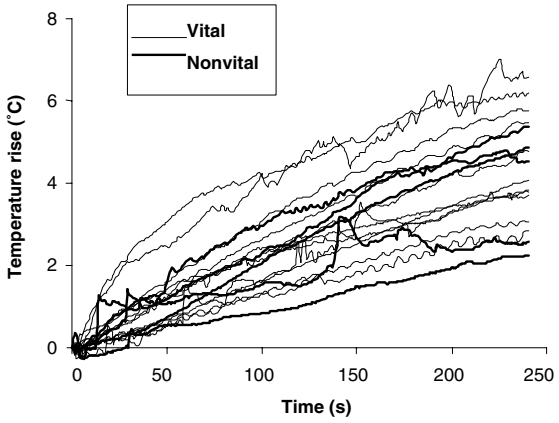

Figure 5 Rewarming temperatures of the 11 vital and five nonvital teeth.

when using physiological flow rates to impose a temperature change within the pulp chamber (see e.g. Fig. 3). Incomplete cooling of parts of these tissues would allow these areas to act as heat sources during the rest of the experiment.

As the physiological rate of blood flow through a tooth is reported to be in the range 12–36 mL h^{-1} (Matthews & Andrew 1995), the laboratory experiments show that this variation could be expected to be reflected in the surface temperature of the tooth. For the same reason, blood flow in this region should also lead to more rapid rewarming after a period of cooling the tooth.

However, it is evident that other factors such as ambient temperature, geometrical factors and heat transfer to and from the surroundings obscure this relationship. The *in vitro* rewarming seen at 0 mL h^{-1} internal flow (Fig. 3) must be due to heat transport from the surroundings and from the roots which were immersed in the heated water bath. However, the rate of rewarming is clearly a function of the flow rate through the pulp cavity, especially when flow rates greater than about 30 mL h^{-1} are used, although the relationship is nonlinear. Figure 4 supports the findings of Fanibunda (1985, 1986a) that the temperature range for vital teeth is so wide that it is not possible to assess tooth vitality from a static reading. However, the results of the present study demonstrate that the same complexity and variability of the thermal environment affect temperature recovery after cooling (Fig. 5). It is only when the conditions are kept as uniform as possible (by comparing vital and nonvital teeth in a symmetrical position in the same mouth) that it becomes possible to separate the two groups. Even this relationship is not completely predictable (Fig. 6), with one of the five pairs showing a quicker return to initial temperature by the nonvital tooth.

The findings from the present experiment do not support Fanibunda's (1986a,b) conclusion that it is possible to estimate the vitality of any particular tooth by measuring the time profile of its temperature response after a thermal event.

One may assume that in the normal circumstance of a closed mouth, the temperature of a tooth is fairly stable. However, it is well documented that when isolated for analysis, the surface temperature of teeth is highly individual (Fanibunda 1985, 1986a), and also strongly influenced by environmental factors (Pogrel *et al.* 1989).

In addition to this inherent variability, the surface temperature also appears to be unstable over time.

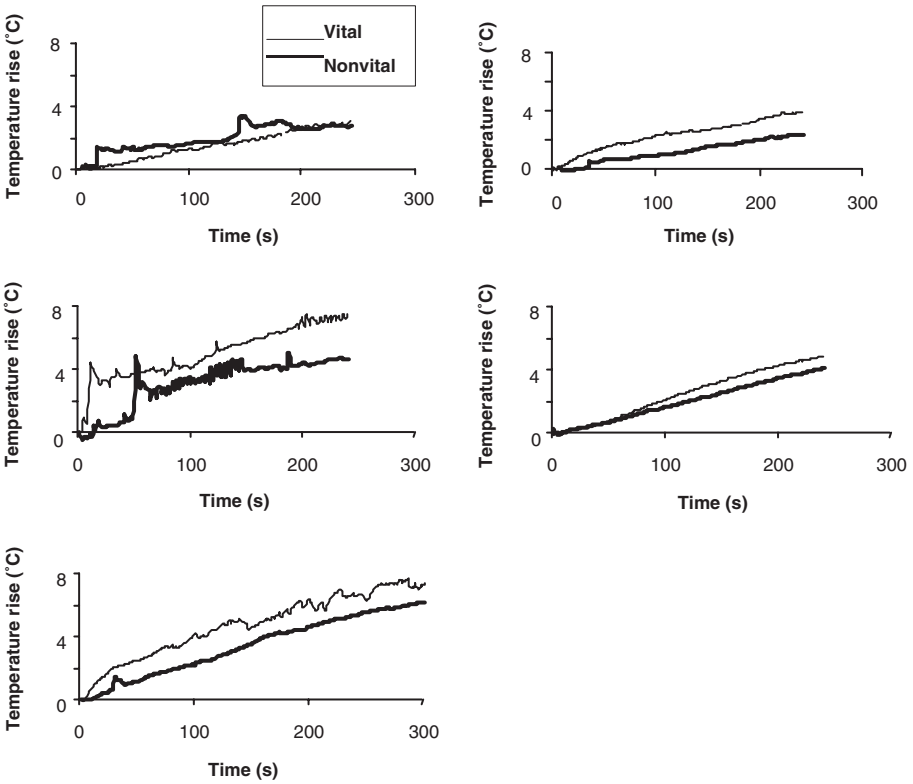

Figure 6 A comparison of the rewarming rate of the five available nonvital teeth with the matching contralateral vital tooth.

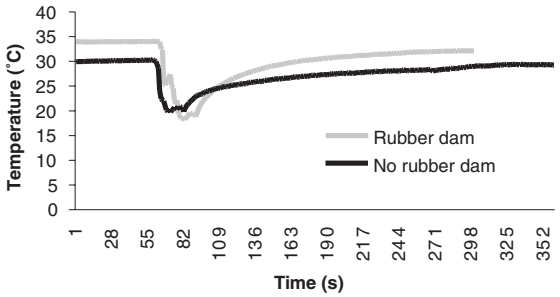

Figure 7 Pilot experiment showing effect of rubber dam isolation on rewarming profile of a tooth.

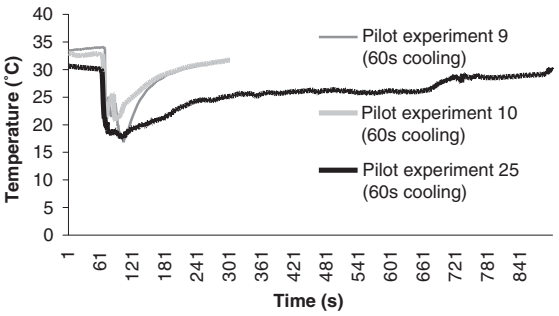

Figure 8 Pilot experiments showing temperatures of different teeth air cooled for different periods.

A slow increase in tooth temperature during cooling by an air jet (Fig. 8) was observed. Even when separated from the oral cavity by rubber dam, and isolation from the influence of respiratory airflow is at a practical maximum this instability is still evident, although over a longer period of time (Kells *et al.* 2000a). Two explanations could account for this slow warming. Heat input to the tooth may increase over this time period, or heat loss from the tooth may reduce over the same period.

This observation leads to the following hypothesis. The temperature of an uncovered tooth is a balance between heat input from the body, and heat loss to the environment. These dynamics are moderated and slowed by the heat storage capacity of the tooth. Heat input to the tooth arises from the pulpal blood flow (if applicable) and from the periodontium, and from the respiration (if warmer). Averaged over a reasonable period, these inputs are constant. Heat loss to the

environment is from: (i) heat radiation; (ii) heat conduction to, and convection of, the surrounding air; and (iii) evaporation, and convection of, water from the tooth's surface.

The determinant of the rates of radiation and of conduction is the tooth surface temperature. If, as seen in our and others experiments, the surface temperature increases, then these routes of heat loss should also increase.

The only factor which can act as a route of heat loss that *decreases* and can adequately account for the effect seen is the evaporation of water from the surface of the tooth. Evaporation of surface moisture was identified by Fanibunda (1986b). However, gradual desiccation of the bulk of tooth would also cool the tooth. This influence would reduce over time, and could account for the slow changes seen in our experiments and in those of Kells *et al.* (2000a). It may also explain why the increase in temperature was more rapid in the present study, as the desiccating action would be greater. A further series of experiments involving cooling of teeth in a controlled humidity environment is planned.

However, in addition to this, it is still possible that noncompliance with the instruction to subjects to avoid mouth breathing may have influenced the results. Despite our equivocal findings in pilot experiments, another avenue worthy of further exploration would be the application of rubber dam to exert greater standardization of the tooth's environment. Nevertheless, it is possible to conclude that tooth surface temperature is not suitable as a simple and robust means to assess tooth vitality in a normal chairside situation.

Conclusion

Currently, tooth surface temperature is affected by too many competing influences for either it, or a time derivative of it, to be used as a simple means to assess pulpal blood flow and the sequelae of blood flow: pulp vitality and potential for healing.

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